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BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: AS-503 S-IVB LOX Tank Overpressurization Problem Case 320

DATE: December 31, 1968

FROM: A. Bresnick

ABSTRACT

A new mission rule for S-IVB LOX tank overpressurization prior to first burn was implemented for AS-503. If tank overpressurization occurred before LET jettison, the rule would have required the crew to abort; after LET jettison, upstage to the S-IVB would have been required. Overpressurization can occur within 50 seconds if either of the cold helium supply shutoff valves remain open, causing the GOX to freeze the tank vent valves closed.

For AS-503, the risk appeared to be minimal, considering the failure criticality and the mission rule implemented. For AS-504, the probability of occurrence appears to be more remote due to an S-IVB pressurization system sequencing change. However, since single point failure modes exist which could cause the overpressurization condition (and the crew has no onboard cues available), it is recommended that consideration be given to retaining the mission rule for AS-504.

(NASA-CR-100247) AS-503 S-4B LOX TANK OVERPRESSURIZATION PROBLEM (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

INTRODUCTION

A new mission rule for S-IVB LOX tank overpressurization prior to S-IVB ignition was implemented for AS-503. If tank overpressurization were to occur the crew would abort prior to LET jettison, and would upstage to the S-IVB after LET jettison. S-IVB LOX tank overpressurization could occur due to any failure which prevented closing of either S-IVB LOX tank pressurization cold helium supply shutoff valve. With continuous cold helium flow into the tank, the ullage pressure would rise to the relief setting of the two vent valves. The vent valves, which are pilot operated, would continue to vent the gas mixture in the ullage space until the cold helium chilled the GOX-helium mixture to a low enough temperature to cause the GOX to freeze. If this were to occur, the frozen GOX could clog the vent valve pilot circuits (Figure 1), lowering the valve main piston actuation pressure causing the vent valves to close.

DESCRIPTION OF THE LOX TANK PRESSURIZATION SYSTEM[6]

The S-IVB LOX tank is prepressurized 3 minutes before liftoff by the GSE which supplies cold helium through the cold helium fill port (See 1 Figure 2), the LOX tank pressurization module 2, the plenum 3, and the heat exchanger bypass orifice 4, into the LOX tank. When the ullage pressure increases to 41 psia, the tank pressure switch 5, sends an electrical signal to close the redundant cold helium supply shutoff valves 6. This completes the prepressurization operation. The LOX tank is pressurized from liftoff to first burn ignition by the cold helium stored in the nine helium tanks 7 (at 3100 psia) located in the S-IVB LH_2 tank. The cold helium flow is commanded on when the LOX ullage pressure drops below 38 psia. This causes the tank pressure switch to open which commands the cold helium supply shutoff valves to open. The cold helium flows into the tank until the pressure reaches 41 psia, at which point the pressure switch commands helium shutoff.

During S-IVB engine operation, the cold helium supply shutoff valves are normally continuously open. The LOX tank regulator backup pressure switch 8 (which also controls the cold helium supply shutoff valves) acts as a backup for the pressure regulator 9 within the LOX tank pressurization module 2. Down stream of the LOX tank regulator backup pressure switch, the cold helium flow is divided into two flow paths. One flow path leads directly to the tank ullage, the other flow path passes through the J-2 heat exchanger 10. The cold helium heated by the J-2 heat exchanger, flows through an orifice 11, is mixed with the cold helium which bypassed the heat exchanger, and the warm mixture flows to the tank ullage. If the tank ullage pressure drops below 38 psia the ullage pressure switch will command the heat exchanger bypass valve 12 to open, sending a larger volume of heated helium to the LOX tank. At 41 psia, the pressure switch will cause the exchanger bypass valve to close, returning the flow to the heat exchanger orifice path.

After S-IVB burn, the LOX tank is vented. Prior to second burn, the LOX tank is repressurized redundantly by an ambient helium supply and an oxygen/hydrogen burner, which is used to heat the cold helium prior to its entrance to the LOX tank. The real time sequencing of the different pressurization cycles is controlled by the S-IVB switch selector.

The LOX tank pressurization or makeup cycle after liftoff and before first burn, was originally intended to makeup ullage pressure decreases which resulted due to increased acceleration. (The effect of acceleration is to increase tank and ullage volume; the LOX also cools the ullage gases causing the tank pressure to decrease, Reference 1).

DIAGNOSIS OF PROBLEM

A. Failure

There are two basic failures, either of which could prevent the cold helium from being shutoff.

(1) Failure of either of the two cold helium shutoff valves to close, or

(2) Failure of an electrical component in the pressure switch circuit to signal excessive pressure.

The cold helium shutoff valves and the tank pressure switch are shown schematically in Figure 2. The tank pressure switch electrical circuit contains several single point failures which could prevent cold helium shutoff or which could initiate inadvertent cold helium flow. These single point failures include:

(1) The LOX tank pressure sensor and its electrical switch,

(2) Relays K-74 and K-30, which control the supply of power to the cold helium shutoff valve coils, and

(3) The coils of the cold helium shutoff valves.

B. Cold Helium Injection

Regardless of the source of the failure, any continuous cold helium flow into the LOX tank before J-2 engine first burn is likely to freeze the vent valves closed. Vent valve freezeup was not considered a problem until recently because it was felt that the cold helium would not mix with the GOX, but that the helium would blanket the GOX preventing the vent valves from being exposed to it. Recent tests at MSFC (Week of December 12) have shown that the tank vent valves will close, and remain closed, in the event of a continuous cold helium flow into the ullage space. (The tests are still being evaluated for their simulation of actual flight conditions, Reference 4).

C. Pressure Rise and Tank Rupture

Figure 3 shows a typical S-IVB LOX tank ullage pressure profile (calculated). The figure shows the delay time of 50 seconds expected from the cold helium shutoff failure until both vent valves freeze closed and the pressure buildup begins. With both vents closed, the tank pressure is seen to rise at a rate of about 1.7 psia/second. At this rate the bulkhead would fail in 17 seconds.

D. Likelihood of Failure

The combined condition of failure of the helium valves to shutoff and subsequent freezing of the LOX tank vent valves has a criticality number of 256, (Reference 2). The pressure switch which is probably the most susceptible of the single point failures has a criticality number of 14, (Reference 2). This switch has not had a bad failure history, and therefore is not considered to be an item of concern.

Effects on AS-503

It did not appear likely that makeup pressurization would be required for AS-503; however, cold helium flow could have been inadvertently initiated by any of several single failure points. A mission rule instituted to insure crew safety was (Reference 5):

(1) Prior to LET jettison, the crew would abort if ground telemetry indicated the following two malfunction cues:

(a) Continuous cold helium flow, and

(b) LOX tank ullage pressure of 50 psia (or saturated at its upper limit).

(2) After LET jettison, the crew would upstage if ground telemetry indicated the following two malfunction cues:

(a) Continuous cold helium flow, and

(b) LOX tank ullage at the vent relief pressure.

There were redundant indications of ullage pressure and cold helium flow available to the Booster Systems Engineer (BSE) at MCC.

In earth orbit, indications of LOX tank pressure were available to the flight crew in addition to the malfunction indications available to the BSE. In this case, the LOX tank could be vented by ground command to open the vent valves, which was not permitted by the software during boost. Continuous cold helium flow would not constitute an undue crew safety hazard in earth orbit.

Effects on AS-504 and Subsequent Vehicles

For AS-504 and subsequent vehicles, the S-IVB LOX tank pressurization makeup cycle will be inhibited until 30 seconds prior to S-IVB first burn (Reference 3). (This is a software change which was not instituted for AS-503 because it would have resulted in a launch delay). If continuous cold helium flow were to occur during this period of time, it would not cause the vents to freeze because the helium would be warmed shortly after engine ignition.

CONCLUSIONS AND RECOMMENDATIONS

For AS-504 and subsequent vehicles, the likelihood of a failure causing continuous cold helium flow appears to be more remote due to the software change which eliminates the pressure makeup mode for early flight. Consideration should be given, however, to retaining the mission rule implemented on AS-503 because single point failure modes still exist which could cause overpressurization.

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Attachments
References
Figures 1-3

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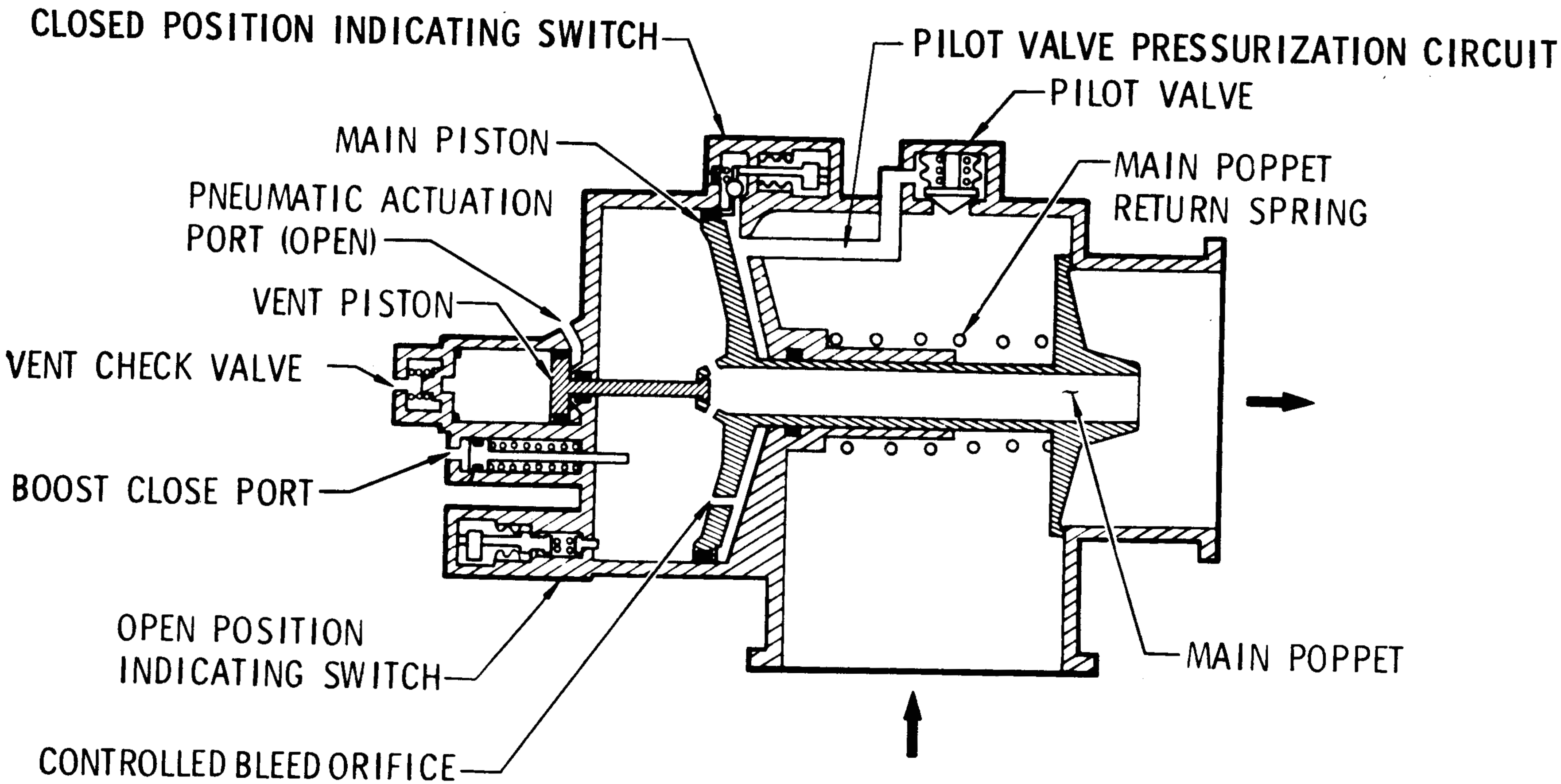

FIGURE I - LOX TANK VENT AND RELIEF VALVE (SCHEMATIC)

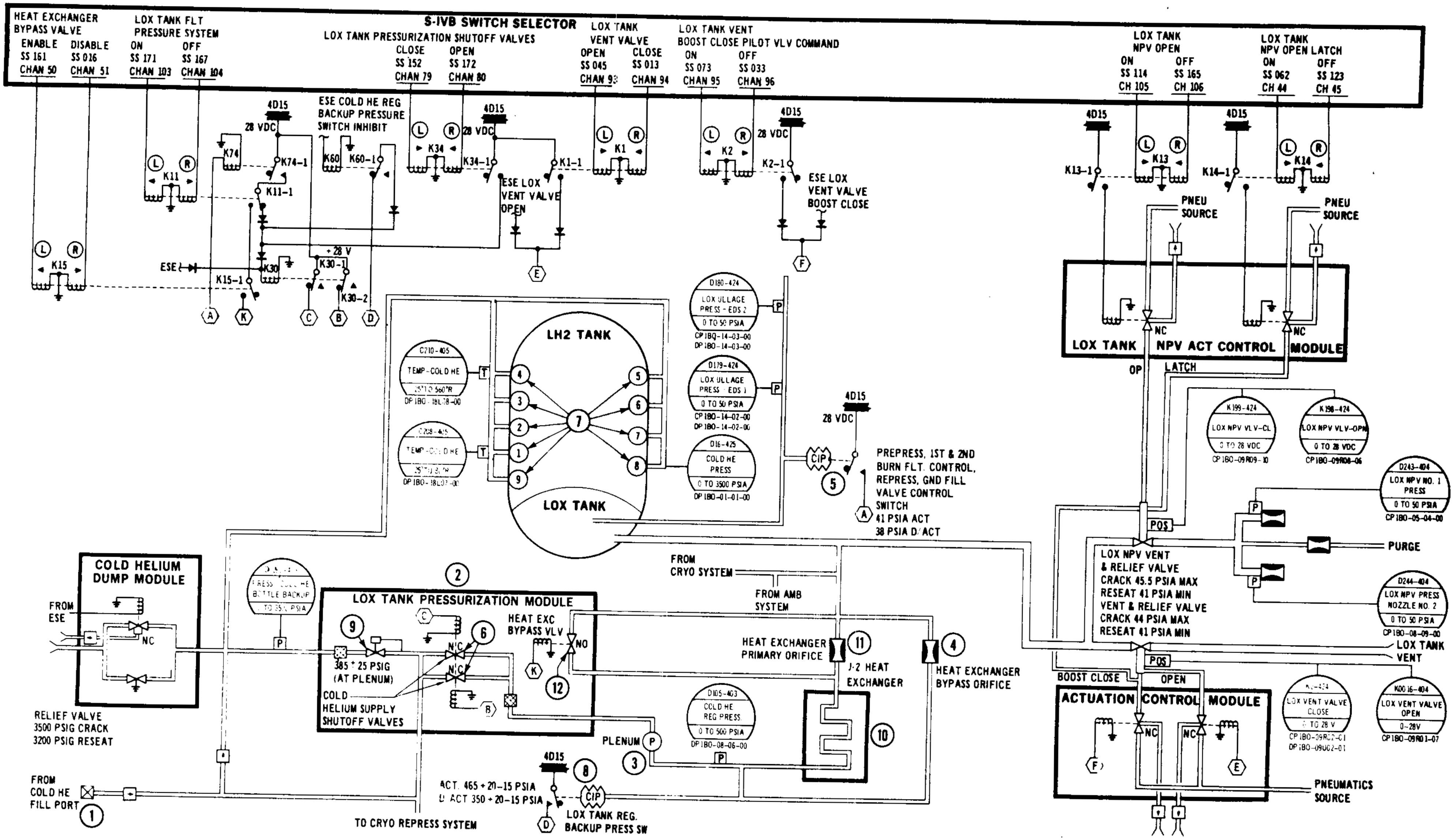

FIGURE 2 - LOX PRESSURIZATION SYSTEM SCHEMATIC - 503N (MANNED) FLIGHT

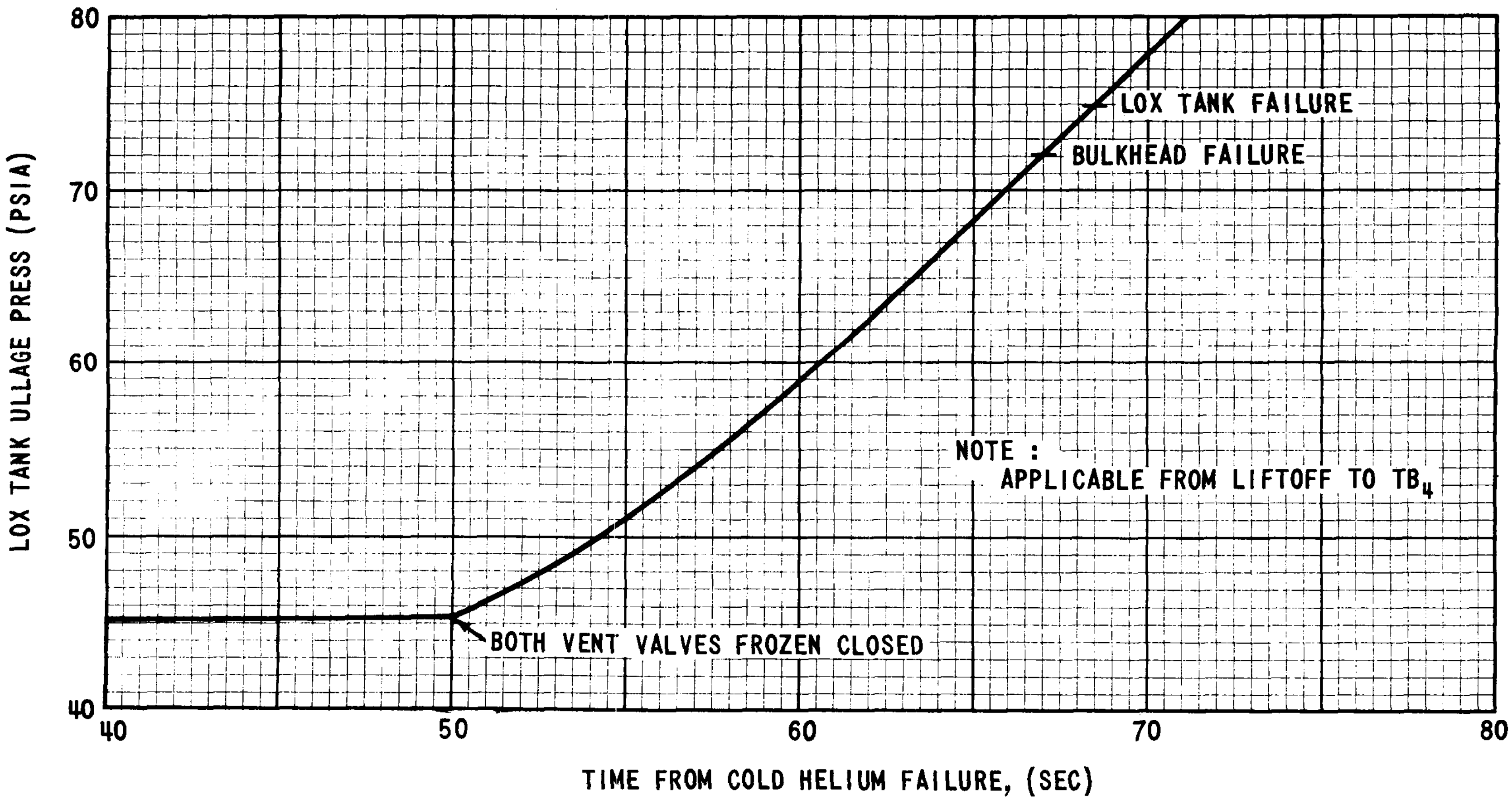

FIGURE 3 - S-IVB-503 COLD HELIUM SYSTEM FAILURE LOX TANK ULLAGE PRESSURE HISTORIES

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